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FOREST WATER YIELD MANAGEMENT OPPORTUNITIES

by

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OPPORTUNITIES

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ABSTRACT:

A real need exists to improve the quantity, timing, and/or quality of water yielded from many forested and nontilled watersheds. The role of watershed management in meeting these needs is described. What can be done, where it appears most needed, and some methods on how it can be accomplished are presented. Modification and alteration of vegetation supplemented by snow fences, and by mechanical and chemical treatments offer some promising possibilities. The practicality of these treatments is indicated by some estimated costs and by comparison of these costs with alternative methods.

FOREST WATER YIELD MANAGEMENT

OPPORTUNITIES 1/

by

E. J. Dortignac 2/

Today watershed management is on the threshold of opportunity. The problem of inadequate water supplies is no longer restricted to the arid and semiarid southwestern United States. All regions of this country have experienced at one time or another serious deficiencies in water supplies. The present critical water shortage in the northeastern United States, a result of a four-year drought in a humid region, exemplifies this. On the other hand, during December 1964 and January 1965 the Pacific Northwest experienced severe flood damage from storms originating on high-elevation forested lands. At the same time the need for improving the quality of streamflow nationwide is now recognized and was recently climaxed by the President's challenging directive to clean up the Potomac River and make it "a model of scenic and recreation values for the entire country."

1/ Paper for presentation at International Symposium on Forest Hydrology, Pennsylvania State University, August 29 - September 10, 1965.

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The contribution that watershed management on forests and adjacent nontilled lands can make toward improving water yields has not received the recognition and attention it deserves. This, perhaps, is a result of reluctance to apply research information to on-the-ground management. Most past efforts in watershed management have been directed at rehabilitation of damaged or deteriorated watersheds -- repairing man's previous mistakes and abuses. Because of the vast acreages of forests in need of repair, watershed protection has likewise received major emphasis. But protection has excluded most or all of the on-site uses on many watersheds -- it has literally locked up these watersheds. A protection forest has meant protection of the natural vegetation to benefit water or soil rather than improve wood, forage, or other plant production (Kittredge, 1948).

Watershed management can play an important role under the present increasing population pressures and the public demand for greater productivity and multiple use of forest and related lands. Scientific prescriptions that utilize the wood, forage, wildlife, and recreation resources as well as improve water yields and control, maintain, or improve soil stability provide the means.

Improvement in water yield timing was studied and started before World War II by the Department of Agriculture. Detailed Flood Control surveys and investigations formed the basis for watershed action programs. Recommended programs in several basins containing extensive noncultivated lands (forest, brush, and grassland) mostly embraced increased fire protection, constructing debris basins in channels, and tree planting. These practices were aimed at reducing flood flows, but the reduction

of erosion and sediment often provided the greatest benefit. The Public Law 566 program is an outgrowth of the earlier Flood Control Program, but major emphasis is now given to structures rather than to vegetation and soil management.

Little has been done to increase water yielded from a watershed until recent years. The Barr report (Barr et al., 1956) led to the Beaver Creek operational program in the Arizona watershed project. This was the first attempt to translate laboratory findings to a field operation to increase annual runoff.

Improvement in water yield quality has been confined mostly to reduction in sediment through soil stability as part of rehabilitation. Present efforts to clean up the water in the Potomac River and to control acid mine drainage offer new opportunities to watershed managers.

With the exception of Flood Control Surveys, very little management effort has been done to quantify pertinent hydrologic parameters, develop watershed prescriptions, predict the effects of vegetation and landscape management, and take practical action to improve water yields. Though research has provided much information, too little of it has been applied.

The classic Wagon Wheel Gap study (Bates and Henry, 1928) reported 37 years ago demonstrated that:

- (1) all trees can be carefully removed from a small stable mountain watershed without causing significant erosion or sediment,
- (2) removal of woody vegetation results in an annual increase in water yield measured as streamflow,

- (3) most of this increase in water yield from a clear-cut watershed in the mountain snow zone will flow during the spring freshet when snowmelting occurs,
- (4) time of peak flow is advanced when a clear-cut area is large (In this study -- greater than 30 times the height of adjacent standing trees).

Later experiments, using the paired watershed approach introduced in the Wagon Wheel Gap study, have more clearly defined the potential contribution that vegetation, soil, and landscape management can make to improve water yields -- in quantity and in timing.

POSSIBILITIES FOR IMPROVING WATER YIELDS

INCREASING QUANTITY

The need to increase the annual quantity of water yielded by watersheds is most pressing in the western United States. The main exceptions are the high rainfall belt along the Pacific Coast from northwestern California to Canada, and the northern Rocky Mountain area. Practically all of the water used in the West originates as precipitation intercepted by mountain masses.

In these mountains the precipitation and water yield normally increase with elevation. But annual evaporation stress is usually reduced with increased elevation because solar radiation is less effective. The shorter growing season, the smaller percentage of possible sunshine, lower temperatures, and lower vapor pressure deficits attest to this. Only wind, a major factor in evaporation losses, may increase with elevation.

Most mountain precipitation falls as snow. It is temporarily stored on the ground during the winter period of low evapotranspiration demand and is released during the late spring and early summer. Snow is more easily controlled than rain. It can be stored, and released by management of vegetation, by snow fences, and by other mechanical means and therefore the snowpack zone offers a good opportunity for increasing water yields.

Forests

Forests in the snowpack zone receive from 20 to more than 100 inches of precipitation annually. From one-fifth to nine-tenths of this incoming moisture may appear as runoff. Conifers predominate. Spruce-fir, lodgepole pine, and pure stands of true fir occupy the highest part of the forested western mountains. Alpine meadowland covered with grasses, herbs, and shrubs provide park-like openings. Above timberline there is considerable bare rock, while low alpine plants (mostly grasses, sedges and browse) grow on favorable locations. Aspen is found growing in stands, a result of fire, or in groves on moist sites. Ponderosa pine grows in park-like stands, often with a ground cover of grass, in the lower snowpack zone in the central Rockies, the Southwest, east slope of the Sierras, and the drier parts of the Northwest.

Water yield can be increased without damaging the quality of water now produced on these watersheds, if it is done carefully and scientifically. The effects of tree cutting on paired watersheds at three locations in the West are given in Table 1. A 26 percent increase in

TABLE 1 -- Effect of Cutting Trees on Streamflow ^{1/}

Watershed	Precipitation	Runoff	Cut-over Area	Water Yield Increase	
				On Watershed	On Cut-over Area
	Inches ^{2/}	Inches ^{2/}	Percent	Percent	Percent
Wagon Wheel Gap	21.1	6.1	29	84	16
Fool Creek	30.0	11.1	37	39	26
No.Fk. Workman Creek	32.0	3.4	11	32	45

^{1/} Source: Bates and Henry, 1928; Goodell, 1958; Rich et al, 1961.

^{2/} Area-inches or acre-inches per acre.

the streamflow of Fool Creek in the Colorado Rockies was caused by clear-cutting 39 percent of the spruce-fir-lodgepole pine in alternate strips over the watershed. Since only 39 percent of the watershed was treated, the actual water yield increase from the cut-over acreage was 67 percent. Replacing White fir-Douglas fir with grass on 80 acres of moist lower slopes and on the alluvial bottom in Workman Creek, Arizona, increased water yield measured as streamflow about 140 percent from the area treated. Increased streamflow on these watersheds did not degrade water quality in regard to sediment.

Greater increases may be possible by arranging the structure of the forest to maximize snow accumulation, minimize interception losses, and protect the snowpack against wind and insolation. Studies in the West have shown an inverse relation between tree density or tree mass and snow accumulation. Generally, the greatest accumulation of snow is in small openings in the forest and the least under dense forest canopy. Thus, clear-cut openings must be fitted to the landscape to produce a favorable microclimate.

Anderson in 1963 proposed harvesting trees in successive narrow strips at right angles to the maximum solar radiation to produce a "wall-and-step" pattern with the wall to the south and steps to the north. This would provide the most shade to the snowpack and reduce re-radiation from trees to the north. Another proposal is to cut L-shaped openings on east- and west-facing slopes so that cold air drainage is trapped in the contour leg of the L (Anderson et al, 1958). Other shapes, even zigzag or curved patterns, may be desirable depending on the landscape and silvicultural requirements.

Obviously, water yield can be increased only from the cut-over segments of a forest type within a watershed. The rotation, method of cutting, and rate of re-growth of vegetation both above- and below-ground will determine the persistence of water yield increases. Clear-cutting will not have the same effect in second growth as in virgin stands of timber. Future yields of water will depend on the vegetation occupying the watershed at any given time -- not on the quantity of vegetation originally removed.

In general, conifers can be altered more readily in stand structure than can hardwoods. Most conifers, being relatively intolerant, are usually single-storied and contain less mass of vegetation from the ground to the top of the canopy. Conifers as a rule do not sprout when the tops are cut or killed; they reproduce from seeding or by planting nursery-grown seedlings. Conifers in the upper snowpack zone grow under a combination of short growing season and low year-round temperatures. Under this severe climate, growth is relatively slow and changes in vegetation may persist for a very long time. Some persistent marks are left on the landscape from old burns. A good example is the uncut watershed "A" at Wagon Wheel Gap, Colorado.

These conifers, with extremely slow growth and lower quality wood cannot contribute as much to the Nation's timber requirements as to its need for water. Once the virgin stand is removed, the potential for producing sawtimber will be small. Moreover, steep and rocky mountain slopes present a real challenge to commercial loggers and to watershed managers concerned with soil stability and water production.

The balloon harvesting technique recently introduced in Canada and the Pacific Northwest offers a useful approach for difficult terrain and for clear-cutting irregular, discontinuous patches or strips of timber. It can appreciably reduce road construction and maintenance. Long yarding distances made possible with the balloon allow logs to be hauled to roads along ridgetops or downslope to roads on the contour. Transporting logs in the air reduces damage to soil, remaining vegetation including young trees, logs, and watercourses.

Where demand for more water yield is great and production of wood is not paramount, small openings might be converted to grass or other smaller-stature, shallow-rooted plants for permanently increased water yields. Tree species that require less water and have less extensive root systems should be favored along the border between forest and openings. Depletion of soil moisture may extend as far as one-half to two or even three tree heights into the openings, depending on species. The pattern of trees and openings should vary to meet the prescribed objectives and the demands on the watershed.

Brush

Many watersheds are covered with brush as the dominant species or as understory vegetation, particularly in the Southwest where the need for water is great. The present value of brush is for soil protection and for food and habitat for wildlife. Converting brush to a vegetation cover that consumes less water but stabilizes the soil can materially increase water yields without economic loss. Thick, dense masses of woody vegetation with extensive and deep roots consume much water by

interception and evapotranspiration. During prolonged drying periods, the mass of woody vegetation becomes highly combustible. Crown fires, once started, are difficult to control.

The Coyote Fire in 1964 north of Santa Barbara, California, provides a classic example. A complete cover of old-growth brush on the Santa Ynez headwaters insured high infiltration capacities and maximized the available soil moisture storage. This reduced the likelihood of flood flows and soil movement during winter rains. Firebreaks and an elaborate fire detection and suppression system were unable to prevent a fire that started outside the watershed near Santa Barbara from spreading into the Santa Ynez Basin. The fire burned 67,000 acres of brush -- about 45,000 acres in the Santa Ynez drainage. The Forest Service acted promptly to convert 10,000 acres of brush to perennial grass on the gentler slopes and in moist situations. Annual or less frequent maintenance will be required to maintain this cover of grass. Breaking up the mass of brush vegetation along watercourses, benches, and gentler slopes with deep soils to complement the existing firebreaks along ridgetops can reduce the chance of major fires, provide an improved habitat for wildlife, possibly provide winter recreation, and increase water production.

Conversion of chaparral-covered watersheds in Southern California to native grasses and forbs doubled the runoff without appreciable increase in erosion (Pillsbury et al, 1961). On the other hand, removal of brush by wildfire on the 3-Bar Watershed in Arizona increased sediment production more than 400 times and runoff only 7 times (Glendening, Pase, Ingebo, 1961).

On steeper slopes, it may be possible to replace brush with low-water-consuming plants in narrow strips on the contour. Desiccants, prescribed burning, herbicides, and mechanical treatments are proven means. The "Tree Eater" (tree and brush masticator), a mechanical self-propelled overland traveler, is practical on slopes up to 40 percent gradient. The thick layer of dead organic material that covers the ground after one pass provides a protective cover to the soil. Follow-up treatments with herbicides will be required with brush that sprouts. The root plow, which cuts brush below the root collar and thus reduces or prevents sprouting will be more effective. But this implement is suitable only in soils free of large rocks. Reduction of vegetation following wildfires offers a good opportunity to convert the most favorable sites to grass; however, continued protection and maintenance are needed for permanence.

In summary, some ways that water yield from forested areas might be increased by reducing the vegetation and/or root mass or by re-arranging the vegetation pattern and structure are:

1. Temporary -- short-lived improvement without additional treatment.
 - 1.1 Thin pole-size stands.
 - 1.2 Cut patch or strip openings in pole stands for pulpwood.
 - 1.3 Harvest sawtimber so that the future yield of water is favored over wood production.
 - 1.4 Create openings in the sawtimber canopy by group selection.
 - 1.5 Prune trees heavily.

2. Permanent -- long-lived improvement with re-treatment or follow-up.

2.1 Change the arrangement of tree canopy.

2.11 Convert uneven-age stands to even-age (clear-cut, and short rotation forestry).

2.12 Favor species that require, consume, and lose the least water.

2.13 Change the structure (wall and step, L-shape openings, etc.).

2.2 Convert stands to other species in large blocks.

2.21 Trees with less crown foliage, less extensive and shallower root system, shorter growing periods, and efficient users of water.

2.22 Replace brush with shallow-rooted herbaceous vegetation.

2.3 Convert to low-growing, low-water-consuming species in small openings or narrow strips (grass, prostrate shrubs, and carpet vegetation).

2.31 on riparian and moist sites.

2.32 on relatively stable land slopes.

2.4 Remove or kill understory woody vegetation -- particularly deep and extensively rooted plants.

Artificial and Mechanical Treatments

Forest management practices can be supplemented by mechanical methods for accumulating and conserving snow water. Falling and recently deposited snow, particularly in western mountain watersheds, is usually

light, platy, and easily transported by wind. When ground winds exceed 10 or 12 miles per hour, snow may be transported in ground blizzards. The entire surface of each snow particle is then exposed to the evaporation forces during drifting. When snow is retained where it falls, or is made to deposit in deep drifts, the area exposed to drying winds as well as to radiation will be reduced.

Artificial barriers or snow fences can be used to induce snow accumulation on windswept exposures in the alpine zone and in large openings in the forest (Martinelli, M., 1965 and Berndt, H. W., 1964). Accumulation of snow in deep drifts on rocky slopes protected from wind and sun can increase water yield. Snow stored in depth over small areas at high elevation will lose much less moisture by evaporation than if stored as water in lower-lying reservoirs.

Application of evaporation suppressants such as hexadecanol and octadecanol may be practical in openings where snow evaporation losses are important and where the ratio of surface area of snow to volume of stored water is small. Daily evaporation losses from snow in open areas were reduced as much as 70 percent by application of 12 pounds per acre of hexadecanol (Anderson, et al, 1963). Water stored in shallow ponds and reservoirs can likewise be conserved by adding monomolecular films.

Another method of accumulating deeper snow is to break off cornices and induce avalanching where these will not cause damage. One mile of cornice in Lake Creek Barometer Watershed was estimated to contain 150 acre-feet of water after snow had disappeared from the surrounding area.

Inducing avalanching and accumulation of snow concentrated in deep drifts on lower slopes can reduce evaporation losses. The natural snow-collecting areas of avalanche zones are thus freed to collect additional snow. The potential of this method to control and increase snow water storage may be gleaned from examples of avalanching induced for safety purposes. In the 1964-65 winter, out of a total of 81 avalanches in a Colorado mountain watershed, 73 were released artificially between November and late May. ^{3/} On the basis of early experience on the Lake Creek Barometer Watershed project, from 1 to 2 acre-feet of snow water may be accumulated by each induced avalanche.

WATER YIELD TIMING

Inadequate attention has heretofore been given to the alteration of vegetation and other means for improving the time of waterflow delivery. Yet there are many opportunities for modifying the timing of streamflow. In some parts of the West where storage is available, an increase in water at any season can be used. Elsewhere, increases during the high-water, spring-melt season may be detrimental.

Floods

The critical need for flood flow reduction is well recognized, but watershed management has thus far contributed only a little of its potential. Large-scale dams and levees have been the main approach to flood control. The part that watershed management can play is discussed by types of precipitation and causes of floods.

^{3/} Letter from K. D. Davidson, Avalanche Control Engineer, Climax Molybdenum Company, Climax, Colorado, June 4, 1965.

Prolonged Rainfall

Large amounts of rain falling on vegetation and surface soils that are saturated will produce high rates of runoff regardless of rainfall intensities. Ordinarily these storms are widespread and may cover a major watershed. Water flows overland or as quick subsurface flow into small or minor channels and then converges to swell the flow in the main channel forming damaging surges of streamflow.

The best opportunity for reducing flood damage from prolonged rainfall is to increase the available storage above- and below-ground. A large mass of vegetation (both live and dead organic materials) will provide storage space for rainfall by interception and cause some loss of this moisture to the atmosphere during prolonged rainfall. But this storage becomes progressively less important as the quantity of rain increases. An extensive and deep root system of vigorously growing vegetation cover can keep the available storage for water in soil and rock near its maximum. Under forest cover, unless compacted by man, animal, or mechanical equipment, infiltration capacities are relatively high.

On the other hand, removal or destruction of large expanses of vegetation by fire, tree cutting, grazing, and other means can contribute considerable water to peak streamflow and flooding. Illustrations of the potential damages that can occur through flood and high flows, when only a small portion of a watershed becomes denuded of vegetation, have been cited (Colman, 1953). Fifteen years of reforestation and protected natural revegetation of formerly cultivated and abandoned fields in White Hollow Watershed, Tennessee, reduced summer peak flows 73 to 92 percent. A more sustained flow has resulted without a significant change in the total

annual runoff (Rothacher, 1953). More recently, TVA reported a reduction in storm peak discharges of about 80 percent and reductions in storm runoff volumes of 50 to 90 percent with the development of a good forest cover on the previously deteriorated Pine Tree Branch Watershed (TVA, 1962).

It is often stated that floods produced during periods of prolonged rainfall can be reduced only by constructing surface structures such as large dams and levees. The belief is that the entire watershed is fully saturated with water on these occasions. Actually, seldom are large watersheds, except rocky headwaters, fully saturated with water, even in major rainstorms. When one considers that the ground water stored in the upper 2500 feet of the earth's crust exceeds that stored in lakes by 50 times, that in rivers by 500 times, and exceeds water stored as soil moisture by 250 times (Wolman, 1962), we gain some insight of the vast underground capacity available for storage of water. The soil near the surface may be saturated, but subsurface flow is often yielded quickly to the streams because the soil profile becomes denser and the rate of downward percolation is reduced with increasing depth. Also, as certain soils and organic materials reach extreme dryness, they may develop a resistance to re-wetting.

Thus, in addition to increasing surface detention and increasing the time for infiltration by building small reservoirs, contour ditches, pits, basins, and other depressions, the opportunities for modification of subsurface storage capacities and transmission rates should be explored. Storage of water underground can reduce evaporation losses.

Ground water recharge operations have been mainly at the points of use in the valleys and lowlands, but there are some real opportunities in mountain watersheds. Subsurface storage capacities in these watersheds have been grossly underestimated. For example, a water balance analysis was made for the Santa Ynez headwaters as part of the Flood Control Survey in 1941. This analysis indicated that this basin temporarily stored about 45 area-inches of water during the wettest rainy season on record--several times more than that estimated by the field survey of soil and rock.

Where the need is great, an effort should be made to induce the water into or through soil layers resistant to water intake and into rock strata, particularly along fault zones, if this water will contribute to deep, usable ground water supplies in the lower valleys.

Vegetation roots and leaf fall can contribute to improve soil porosity but should be supplemented by mechanical treatments, such as soil ripping, deep subsoiling, and deep trenching with a ditch digger to provide contact with substratum recharge areas. Partial filling of soil openings with plant materials can prolong the usefulness of mechanical treatments.

Melting Snowpack

Melting of the deep snowpack is responsible for high spring volumes of flow. Reservoirs in the West impound a large part of this flow for use later in the season. But when deep snows melt rapidly, particularly when heavy rain contributes to melt and flow, the water released may cause out-of-bank flows from the headwaters to the downstream valleys.

Vegetation management supplemented by artificial or mechanical methods can reduce these flood flows. In general, a dense mature forest will contain much less water in the snowpack and will release melted water at much slower rates than large openings protected from wind, but not from solar energy. Intermediate amounts of vegetation mass resulting from various types of cutting will produce intermediate rates of melting. Removal of trees and other vegetation will increase the rates of melt and advance the date of snow ablation in proportion to the quantity of vegetation removed and with the mass, structure, and pattern of vegetation left in place. Timber harvesting may either increase or decrease peak flows depending on weather conditions. At Wagon Wheel Gap the rate of flow at the peak was increased 60 percent by cutting, whereas at Fool Creek, peak flow rates averaged 50 and 45 percent higher in 1956 and 1958 and 23 percent lower in 1957.

Accordingly, the watershed manager has an opportunity to cut over or plant vegetation in large watersheds so as to flatten the flood peaks caused by snowmelt. The objective should be to desynchronize the snowmelt from the various exposures and subwatersheds. First one must determine the existing synchronization of runoff and then prepare a prescription fitted to the landscape to change the timing. In general, melting should be advanced at lower elevations and retarded at the higher elevations. Within these zones, melting from south and west aspects might be advanced enough over that from north and east aspects to reduce peak discharges in the main channels. The exact pattern must be scientifically designed for an improved yield of runoff during the years of maximum snowfall.

Artificial barriers and other physical methods can help greatly to reduce flood peaks. When snow is induced to accumulate in drifts on slopes protected from the sun in the alpine above timberline and in large open meadows and parks rather than on exposed locations and at lower elevations, a delay in snowmelt will result. Snowmelt from large accumulations of snow in drifts may be retarded by application of sawdust and other materials. Where snowmelt needs to be advanced to disrupt synchronization of flows, additions of dark material such as charcoal dust may be used.

Rain-on-Snow

Rain-on-snow has produced large floods in the Pacific Coast States, in the Northeast, and in the northern States. The effect of management on these floods is complicated and must be evaluated on each watershed. Important factors to consider are soil moisture deficits, susceptibility to soil freezing, and quantity of snow remaining on the ground. When rain falls on deep snows, it may be retained within the snowpack, whereas shallow snowpacks may be released as runoff along with the rainfall.

Frozen Soil

Soil freezing can cause high rates of stream discharge and flood flows. Floods from this source have been most common in the northern part of the United States east of the Continental Divide. However, floods caused by frozen soil have also occurred in eastern Oregon and Washington, and may have also contributed to recent floods in western Oregon and north-coastal California.

Opportunities for preventing or reducing floods from this cause appear promising. Frost formation is influenced by type and condition of vegetation and moisture in the soil. Porous soils and porous humus layers are less susceptible to frost formation than dense soils and compacted humus layers. Accordingly, fine-textured soils and inorganic soils are subject to freezing. Also, a deep snow cover forms a good insulating blanket against freezing air temperatures.

Vegetation cover will affect the condition and moisture in the soil and the amount of snow on the ground during freezing weather. The role of vegetation depends on the species composition, vegetation structure, humus type and content, root channels, evapotranspiration, nocturnal radiation, and other factors.

Frozen soil may occur in burned-over areas, other large openings, and on south and west aspects, when early-season melting of snow is followed by a prolonged temperature drop.

Scientific management based on observed conditions on individual watersheds and supplemented by careful evaluation of long-term records can contribute to reduction in flood flows from this cause.

High-intensity Rainstorms

Thunderstorms occur in the West, Midwest, South, Southeast, and Mid-Atlantic and can produce flash floods even when rainfall duration is short. When convection storms exceed a 30 minute duration and rainfall rates exceed two or three inches per hour, flash floods will occur unless the soil infiltration capacities exceed these rainfall rates or reservoir storage is provided.

On watersheds where low magnitude but intense storms produce overland flow, storage of water on vegetation surfaces and man-made depressions can reduce or even eliminate floods. As the rainfall quantities increase the effectiveness of vegetation, structures, and land treatments will be lessened. The same opportunities described under prolonged rainfall apply here.

The objective is normally to increase the infiltration capacity of the soil so as to convert overland flow to soil moisture recharge and to less rapid discharge to the streams. Interception storage by vegetation and storage in man-made depressions, both small and large can contribute materially to reduction in flood flows. The longevity of depression storage is dependent on size-- the smaller depressions are ordinarily short-lived.

Even a relatively simple mechanical operation such as soil ripping can have a major effect on surface runoff. On semi-arid New Mexico rangeland where 98 percent of the soil surface was exposed to high intensity rainfall impact, soil ripping at seven-foot intervals approximately on the contour, reduced surface runoff 97 percent the first year after treatment and 83 percent in the third year (Dortignac and Hickey, 1963).

Low-flow Augmentation

Water yield everywhere in the United States is greater in the spring and early summer than toward the end of the active growing season. Consequently, unless adequate storage of water is provided in reservoirs behind man-made dams, there is need to augment low flows. This need is greatest on watersheds supplying water to municipalities. There are several methods to do this.

Riparian and Phreatophyte Vegetation

In the forest belts of the western mountains and for some distance below, alders, maples, mountain ash, aspen and willows are found growing along the watercourses. Lower down, cottonwoods and sycamores become more prominent. In arid and semi-arid regions the channels are often lined with tamarix, seepwillow, and mesquite. All of these species use water in what is generally considered to be excess--even wasteful (Croft, 1948, Rowe, 1963, Young and Blaney, 1942). Water yield can be increased by (a) substituting species that use less water, (b) mowing or chemical spraying of phreatophytes to reduce foliage mass, (c) thinning vegetation by cutting individual trees or severe pruning of branches and roots, (d) applying evaporation suppressants, and (e) diverting water by piping or pumping to lower the water table.

It has been estimated that about one-fourth of the water now used by phreatophytes in the 17 western States could be saved--amounting to more than 6 million acre-feet of water. This estimate appears overly optimistic, particularly in view of the increasing importance of the fish, wildlife, recreation, and natural beauty. Removing trees along the borders of streams might raise the water temperatures beyond the safe limit for game fish. Streamside and lakeside trees are important for wildlife, recreation, and esthetic values. But again, removing all trees over a large or extensive area usually is not sound management and therefore unlikely to gain public acceptance. Reducing the vegetation mass by thinnings, defoliation, and other means during critical periods may be more compatible.

Snowpack Management

To retard melting of snow and prolong its contribution to streamflow later into the summer involves both the amount of snow in storage and its rate of release by melting. Tree cutting and removal will tend to increase the rate of snow melting. According to Kittredge (1953), the daily rate of melting was about 0.1 inch of water more in the open than under the forest. Late season yields can be increased if the openings are kept small, $\frac{1}{2}$ to $1\frac{1}{2}$ times the height of adjacent trees, so that the entire opening will be shaded.

At Wagon Wheel Gap, 16 percent of the increased flow left the watershed after July 10 and raised summer streamflow about 10 percent. At Fraser Experimental Forest, timber cutting likewise increased streamflow throughout July, August, and September. On forested watersheds on the western slopes of the Oregon Cascade Range where annual precipitation approximates 94 inches, clear-cutting 30 percent of one watershed caused a 12-28 percent increase in low late-summer flows, while removal of trees from 80 percent of another watershed increased low flow by 85 percent. Under these conditions vegetation appeared to exert a minimum influence on high streamflow (Rothacher, 1965). Likewise, at Coweeta, another well-watered area, percentage increases from cutting were greatest during the months of low streamflow (September-December) when water shortages are most acute (Meginnis, 1959 and Johnson and Meginnis, 1960). But forest management practices do not provide the only means for altering the rates and timing of snowmelt.

The alpine zone above timberline covers 10 million acres in the West. The use of artificial barriers fitted to the landscape in accordance with prevailing wind direction and velocity can increase the amount of snow trapped in natural catchment areas and can hold snow on windswept openings. Holding more snow at these high elevations can prolong the late-season contribution to streamflow.

Melting glaciers and late-lying snowdrifts can be accelerated by addition of dark materials. Solar energy can be absorbed (90 percent or more) by coating ice and snow with dark materials such as carbon dust, soot, finely powdered coal, and powdered organic matter.

Glaciers in the State of Washington store from 40 to 50 million acre-feet of water, some of which might be released in drought years to meet water shortages. Inducing glacier melting by scattering dark materials in various forms over glaciers may be practical. About $\frac{1}{4}$ lb. of carbon dust per 100 sq.ft. is needed. An increase in late-season streamflow of 11 percent in the Lewis and White Salmon River Basins was estimated to be worth \$370,000 in power that could have been generated by hydroelectric plants.

The practicality of this procedure is indicated by experiences in China. The Tuhuang peasants have been fighting drought since the Ching Dynasty by liberating water from ice and snow in the Chilean mountains (Hahn, 1961). Grass and leaves are collected, burned, and the ashes are spread over the glacier surfaces.

WATER QUALITY

Forested watersheds, unless abused, ordinarily produce relatively good-quality water. On certain watersheds, chemical contamination of surface and subsurface waters is a natural phenomenon -- not man-induced. But, the constituents in natural raw water from forests may not meet the quality required for many uses.

The need for good quality water is most pressing on watersheds supplying water to municipalities and industries. Surface water supplies are tapped by about 6,000 communities in this country. About 40 million acres of National Forest lands provide surface waters to 1100 communities which contain about 17 million people (Beattie, 1963).

On these lands watershed managers should be concerned with the physical, chemical, biological, and radiological properties of the raw water produced. Before many decades have passed the public will no doubt demand complete processing (chlorination, coagulation, flocculation, and filtration) of domestic water supplies. Accordingly, future management of these lands will be aimed at reducing the costs of processing water and safeguarding storage reservoirs.

Sediment

The control of suspended and bedload sediment is an important consideration, not only in regard to the loss of capacity in impounding reservoirs but also in reference to the usability of water at the point of intake. Alum is used to flocculate fine colloidal sediment. A given reduction in suspended sediment can reduce the quantity of alum required

by a similar amount. Savings from smaller capital outlay for settling basins and filter plant units, lower power, labor, and other costs for backwashing filters, and flushing and cleaning settling basins can reduce treatment costs. A 25 to 30 percent reduction in suspended sediment can reduce the cost of finished water at the filter plant by about \$10 per million gallons.

Logging can be done without an increase in the production of silt, as mentioned earlier. An intensive selection cutting on the Fernow Experimental Watersheds with carefully planned skid roads had maximum turbidities (mostly soil particles) of 25 units as compared to the control of no logging with 15 units. In contrast, commercial clear-cutting with unplanned skid roads had maximum turbidities of 56,000 units (Reinhart et al, 1963). Skyline yarding systems can move logs from steep slopes without severe soil disturbance and should be used where a reduction in sediment is needed.

Evidence that streamflow turbidities can be decreased by watershed management practices on large watersheds was cited by Albert and Spector, 1955. The average annual turbidity of the Chattahoochee River (928,000 acres) declined from a maximum of 400 to a low of 65 parts per million -- a result of the improvement in the hydrologic condition of the forest and tilled land in the watershed.

The need for the control of sediment in surface waters is particularly important in the West. Sediment transportation and deposition may cause damage by reducing reservoir capacities; aggrading stream channels;

covering land, crops, roads, and other structures; increasing maintenance of channels, ditches, and drains; increasing water wasted by non-beneficial vegetation and mud flats; impairing recreation and aesthetic values; and destroying fish and fish habitat. The annual wholesale value of one acre of streambed gravels used for spawning by salmon was estimated at \$65,000 to \$90,000 in 1946 to 1948 (Paulson, 1955).

Acid Drainage

Acid drainage from mines and mine workings is endangering community water supplies, destroying vegetation and fisheries habitats, and killing fish. Water rendered acid by flowing over exposed coal surfaces is hindering full development in at least seven Appalachian States, most of them already depressed. Control methods include mine sealing, diversion of surface waters flowing into mines and diversion or control of acid drainage issuing from them. Although the rehabilitation of these mined areas and the control of acid drainage is an urgent need, it may be more important to prevent damage on unspoiled lands scheduled for future mining operations.

Watershed managers can help prevent damaging acid drainage during and following mining operations, if a detailed hydrologic survey, analysis, prescription, and plan is completed in advance of a contemplated mining operation. The survey should identify the kinds and the subsurface location of toxic materials before any excavation of soil is undertaken. Precautions should be made to avoid exposure of toxic materials to the atmosphere and to replace them in the earth to avoid

future damages. If soil excavated in mining and road-building is handled properly, the problem of acid drainage can be prevented. Also, advance planning may improve hydrologic behavior on some strip-mined areas. Tight compact subsoils, fragipan, hardpan, and claypan horizons can be modified to improve subsurface water movement, thus reducing flood flows and augmenting low flows.

Waste Stabilization Ponds and Recirculating Flows

Water stabilization ponds and recirculating streamflow are two methods that can be employed by watershed managers to improve water quality as to biological constituents, organic materials, physical properties, and certain inorganic compounds. These methods may have application on watersheds supplying waters for domestic and industrial purposes.

Heat

Cutting and removal of vegetation from watershed slopes and along watercourses can increase the temperature of surface waters. Where streamflow temperatures are critical to survival of game fish this factor becomes important. Surface waters can be cooled by impounding and releasing outflow of water from the bottom of deep reservoirs.

CONCLUSIONS

A water yield improvement program should be implemented on a watershed-by-watershed basis. There may be a tendency to generalize from specific research findings and to apply these data without consideration of the climate-soil-rock-plant-water relationships on watersheds selected for

intensified management. This can lead to failure, and in some cases disaster. Each watershed in need of water yield improvement must be inventoried, characterized hydrologically, and a scientific prescription prepared. Also, the hydrologic survey, analysis, and prescription of the watershed should identify the flood, sediment, debris, pollution, avalanche, and landslide sources and locations and prescribe the protection and rehabilitation needs.

Improving the quantity, timing, and/or quality of water yielded from forested and related watersheds will require an expenditure of funds. The accumulated annual or periodic maintenance costs can be expected to exceed the initial cost of treatment. An estimate of management, treatment, and maintenance costs of various procedures proposed for increasing the quantity of water yielded follows:

<u>Treatment</u>	<u>Cost per acre-foot of water produced (Dollars)</u>
Modifying Harvest Practices in Commercial Timber Zone	2 - 3
Chaparral Conversion	4 - 6
Riparian Treatment	4 - 5
Snow Fencing	6 - 7
Inducing Avalanches	3 - 6

These costs ranging from about \$2 to \$7 per acre-foot of water produced are comparable to the \$4.50 per acre-foot cost of phreatophyte (mostly salt cedar) control in the Pecos River (PL 88-594), and are considerably less than the almost \$100 per acre-foot predicted cost of

desalination by 1980. But increasing the annual quantity of water yielded from high-elevation mountain watersheds provides benefits in addition to the increased volume of water produced for downstream use. The augmentation of low flows in the streams may save the fisheries, contribute to natural beauty and to improved recreation. Existing water distribution systems can be utilized. A new system may require \$70 or more for transporting an acre-foot of water 1000 miles. Lifting an acre-foot of water 1000 feet may cost another \$50 - \$60 per acre-foot. Thus it may be more feasible economically to expend large sums of money to create more water where transmission facilities are already available than to produce water in areas that require development of new distribution systems.

On most watersheds it is possible to: (1) increase the portion of precipitation yielded to streamflow and/or deep ground water recharge; or (2) improve the quality of water; or (3) convert runoff to a more even daily distribution throughout the year. One or perhaps two of these objectives might be partially met on a given watershed -- possibly at some sacrifice to the others. Major emphasis should be given to meeting the objective most needed. This will depend on the present and future economic-social conditions and on the existing and proposed structures and facilities within the watershed and at the affected downstream locations.

Opportunity lies ahead. Watershed managers should provide the necessary skill and leadership.

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